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AF/SSD-TR-61-8 R-3135

NITROGEN TETROXIDE HANDLING MANUAL

ROCKETDYNE
A DIVISION OF NORTH AMERICAN AVIATION, INC.
6633 CANOGA AVENUE, CANOGA PARK, CALIFORNIA

CONTRACT AF33 (616)-6939
PROJECT No. 3148
TASK No. 30196

SEPTEMBER 1961

ROCKET TEST ANNEX
SPACE SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
EDWARDS AIR FORCE BASE, CALIFORNIA

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FOREWORD

This manual is one of the four propellant handling manuals prepared under Contract AF33(616)-6939, Supplement 1, PN 3148, TN 30196. The administrative and technical direction of this effort was provided by Messrs. F. S. Forbes, T. Marshall, and J. H. Smith of the AFFTC, Edwards Air Force Base, California. The manuals were prepared by the Analysis and Equipment Group of the Rocketdyne Engineering Department.

The propellant handling manuals were titled and identified as follows:

AF/SSD-TR-61-7	Hydrazine Handling Manual
AF/SSD-TR-61-8	Nitrogen Tetroxide Handling Manual
AF/SSD-TR-61-9	Chlorine Trifluoride Handling Manual
AF/SSD-TR-61-10	Pentaborane Handling Manual

A group of four design-criteria manuals were also prepared under Contract AF33(616)-6939, Supplement 1, PN 3148, TN 30196. These manuals were titled and identified as follows:

AF/SSD-TR-61-6	Mechanical System Design-Criteria Manual for Hydrazine
AF/SSD-TR-61-5	Mechanical System Design-Criteria Manual for Nitrogen Tetroxide
AF/SSD-TR-61-4	Mechanical System Design-Criteria Manual for Chlorine Trifluoride
AF/SSD-TR-61-3	Mechanical System Design-Criteria Manual for Pentaborane

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INTRODUCTION

This manual presents directly usable information for the safe handling of nitrogen tetroxide. The material presented is that evolved from both applicable experience and a thorough evaluation of the available literature, especially that originating from the propellant manufacturer.

The need of reliable information for the safe handling of high-energy propellants is self-evident. Although pertinent literature abounds, the application of the published handling techniques to actual situations cannot be successfully realized in most cases. This frustrating situation can be attributed to the fact that most propellant handling information is obtained as a byproduct of hardware development programs. This manual represents one of the first concerted research efforts to formulate safe propellant handling techniques.

The material covered in this manual is that which is considered essential for the safe handling of the propellant. This material is presented in a very simple and direct manner to make it usable to all personnel involved in propellant handling operations. In addition, the techniques included are expected to provide additional background to the designer of storage and handling systems for nitrogen tetroxide.

The safety practices in the manual are based on the principle that the prevention of hazardous situations is the most important consideration for the safe handling of high-energy propellants. However, it is acknowledged that a completely hazard-free facility cannot be ultimately realized; therefore, serious consideration is also given to the control of any hazardous situation that may arise.

This manual consists of eleven sections, each section dealing with a specific subject such as properties of the propellant, materials of construction, handling procedures, and others. This arrangement allows the user to obtain specific information expeditiously.

1.0 GENERAL DESCRIPTION

Nitrogen tetroxide (N_2O_4), also known as dinitrogen tetroxide, NTO, nitrogen peroxide, or liquid dioxide, has a characteristic reddish-brown color which is caused by the presence of nitrogen dioxide (NO_2) in varying amounts, depending upon the temperature and pressure. This propellant can be harmful when inhaled as a vapor and can cause serious burns when the liquid comes in contact with any part of the body, internally or externally. Since nitrogen tetroxide is a very reactive oxidizer, it can cause fires with many combustible materials.

As a storable liquid oxidizer, nitrogen tetroxide offers for liquid-fueled rockets the readiness approaching that of solid propellant rockets. Its oxygen content, about 70 percent by weight, gives nitrogen tetroxide a performance approaching that of liquid oxygen. Under similar operating conditions, the theoretical specific impulse of the nitrogen tetroxide-hydrazine combination is 292 seconds and that of the liquid oxygen-hydrazine combination is 313 seconds.

Nitrogen tetroxide boils at approximately 70 F. As a result, refrigeration is not required to keep it in the liquid state in conventional moderate-pressure vessels. When stored and transferred in clean, airtight, moisture-free systems, and handled by trained, conscientious personnel, nitrogen tetroxide need present no serious storage or handling problem.

2.0 PROPERTIES

2.1 General Properties

Because the nitrogen tetroxide propellant exists as a mixture of nitrogen tetroxide (N_2O_4) and nitrogen dioxide (NO_2) in equilibrium, the properties presented below pertain, for the most part, to mixtures of the tetroxide and the dioxide. However, the properties are reproducible since the chemical equilibrium between the two oxides is established almost instantaneously.

2.1.1 Appearance

Nitrogen tetroxide has a characteristic reddish-brown color in both liquid and gaseous phase. In the solid state, nitrogen tetroxide is colorless.

2.1.2 Odor

Nitrogen tetroxide has an irritating, unpleasant, acid-like odor.

2.1.3 Chemical Composition

The composition of nitrogen tetroxide established by Military Specification MIL-P-26539, expressed in percentage by weight, is as follows:

N_2O_4 assay	99.5 min.
H_2O equivalent	0.1 max.
Cl as NOCl	0.06 max.
Nonvolatile (ash)	0.01 max.

2.1.4 Chemical Activity

Nitrogen tetroxide is a very reactive, toxic oxidizer. It is insensitive to mechanical shock, heat, or detonation. Although it is nonflammable with air, it can support combustion of ordinary combustible materials.

In oxidation reactions, nitrogen tetroxide resembles ozone and hydrogen peroxide. It is hypergolic with high-energy fuels such as hydrazine and unsymmetrical dimethylhydrazine at atmospheric pressures.

Several nitrogen tetroxide reactions are of considerable importance to the propellant handler since they constitute the basis for propellant neutralization, disposal, and decontamination operations. Some of the typical reactions are as follows:

1. Reaction with water. Nitrogen tetroxide reacts with water to form nitric acid as follows:

   $$N_2O_4 + H_2O \rightarrow HNO_3 + HNO_2$$

   The nitrous acid undergoes decomposition:

   $$3HNO_2 \rightarrow HNO_3 + 2NO + H_2O$$

2. Reaction with sodium carbonate and sodium hydroxide. The nitrogen tetroxide reaction with sodium carbonate and sodium hydroxide follows the following equations, respectively:

   $$N_2O_4 + Na_2CO_3 \rightarrow NaNO_3 + NaNO_2 + CO_2$$

   $$N_2O_4 + 2NaOH \rightarrow NaNO_3 + NaNO_2 + H_2O$$

2.2 Physicochemical Properties

Molecular Weight	92.016
Boiling Point	70.07 F
Freezing Point	11.84 F
Specific Gravity	1.447 at 68 F
Density	90.34 lb/ft^3 at 68 F
	12.08 lb/gal at 68 F
Gas Specific Gravity	3.40 (air=1) at 70 F and 1 atm
Vapor Pressure	5.1 psia at 32 F
	14.7 psia at 70 F
	35.3 psia at 104 F
Viscosity	2.84×10^{-4} lb/ft-sec at 68 F
Heat of Formation, liquid	-12,240 Btu/lb-mol at 77 F
Heat of Fusion	68.5 Btu/lb at 11.8 F
Heat of Vaporization	178 Btu/lb at 70.07 F
Heat Capacity	0.367 Btu/lb-F at 62 F

The specific gravity and vapor pressure of liquid nitrogen tetroxide as a function of temperature are presented in Fig. 1 and 2, respectively.

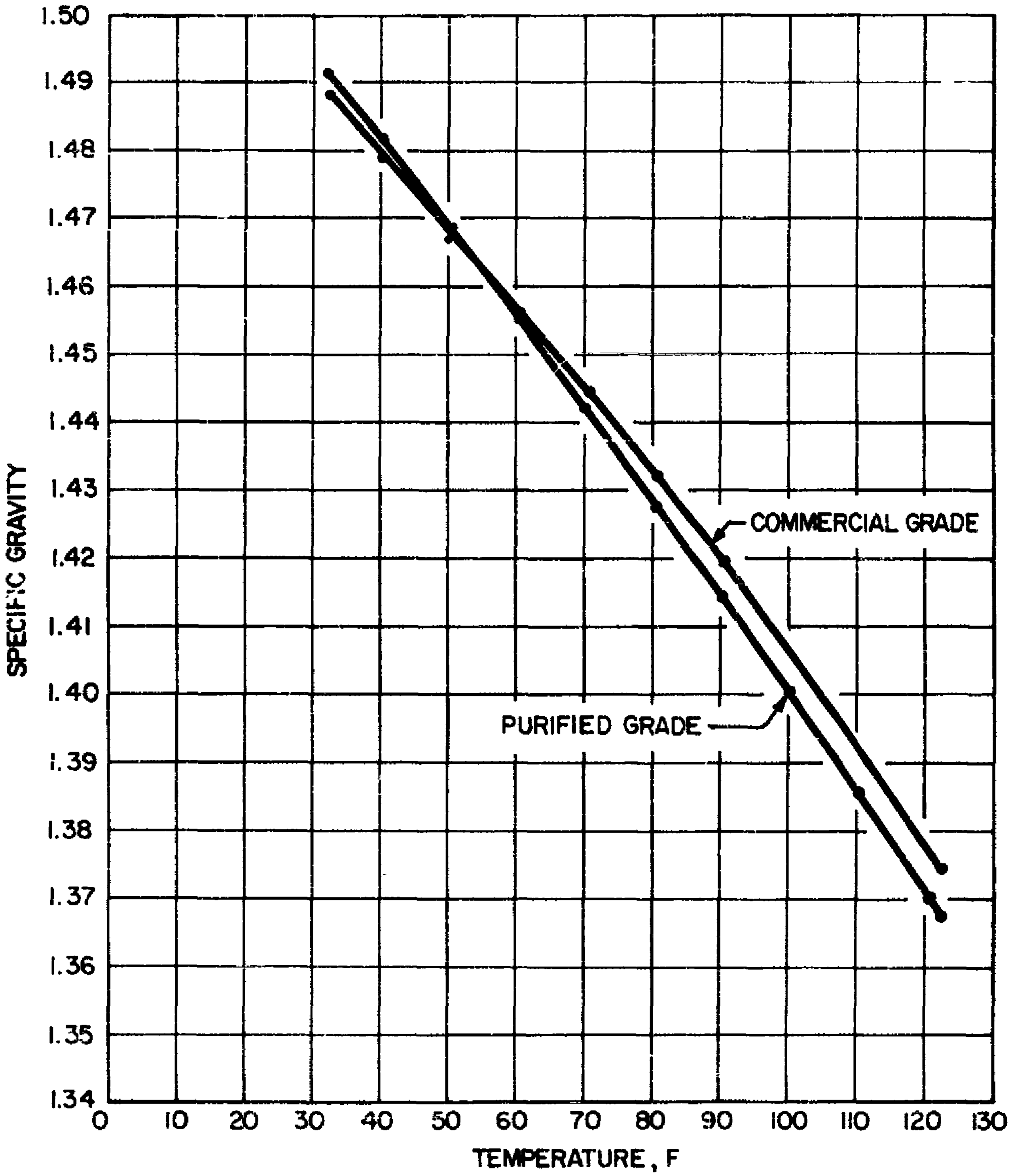

Figure 1. Specific Gravity of Nitrogen Tetroxide

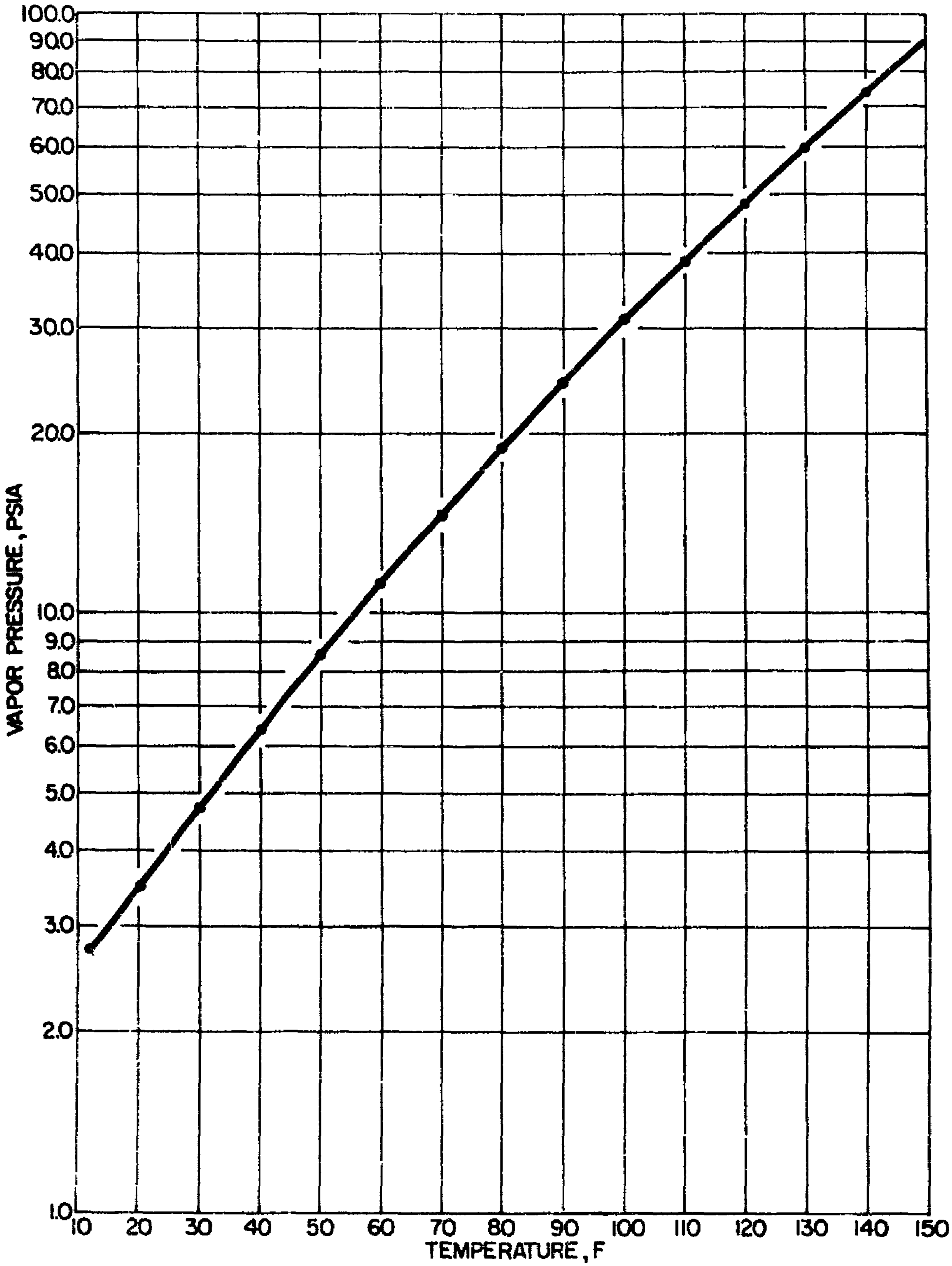

Figure 2. Vapor Pressure of Nitrogen Tetroxide

3.0 MATERIALS

3.1 Materials Compatibility

Nitrogen tetroxide is compatible with a wide spectrum of materials of construction. However, considerable care must be exercised in selecting suitable materials due to the reactivity of the propellant and the need to prevent leaks and spills. In addition, the compatibility of several materials of construction with nitrogen tetroxide depends upon the amount of water contamination present in the propellant.

Nitrogen tetroxide reacts with water to form nitric acid which is more corrosive to most materials of construction than nitrogen tetroxide itself. Therefore, all nitrogen tetroxide systems and components must be absolutely dry.

3.1.1 Compatible Materials

The following materials and lubricants have been found to be compatible with nitrogen tetroxide:

Aluminum Alloy No. 1100
Aluminum Alloy No. 5052
Aluminum Alloy No. 6061
Aluminum Alloy No. 6066
Aluminum Alloy No. 356
Aluminum Alloy No. B356
Aluminum Alloy Tens 50
Stainless Steel AISI 300 Series
Stainless Steel AISI 400 Series
Stainless Steel AM-350

Stainless Steel AM-355

Stainless Steel 17-4 PH

Stainless Steel 17-7 PH

Iron-Base Superalloy A-286

Iron-Base Superalloy 16-25-6

Inconel-X

Chromium Plating

Teflon

Teflon filled with asbestos or glass

Teflon-fiberglass (LNP)

Viton A

Viton B

NA2-205-2 (Alochlor-1254 Monsanto)

Graphite (dry)

Molycote Z (binderless)

3.1.2 Materials for Limited Service

The following materials have been found to be satisfactory for limited service in nitrogen tetroxide:

Mild Steels

Fluoro-Silicone Rubber (LS-53 Series)

Polyethylene

Keroseal

Saran

NOTE: Since these materials are attacked by nitrogen tetroxide under some expected conditions or time duration, their use is not recommended.

3.1.3 Incompatible Materials

The following materials and lubricants have been found to be incompatible with nitrogen tetroxide and must not be used:

Aluminum Alloy No. 2024	Johns-Mansville Packing No. 60
K-Monel	Johns Mansville Packing No. 76
Brass	Kel-F Elastomer
Bronze	Mylar
Silver	Buna-N
Copper	Hypalon
Titanium	Dow Corning Lubricant No. 55 (MIL-G-4343)
Zinc	
Cadmium	Oxylube
Nickel	MIL-L-6086
Micarta	DC 11
	MIL-L-25336

3.2 Preparation of Materials

All components of a nitrogen tetroxide transfer and/or storage system must be properly prepared prior to installation. Preparation procedures consist of rendering the components chemically inert to the propellant.

Items such as valves, pumps, etc., cannot be cleaned in the assembled state since solvents may damage nonmetallic components or residues may be trapped in inaccessible areas. Consequently, the cleaning of these items must be done before the component parts are assembled.

The preparation of materials generally consists of degreasing, descaling, passivating, and drying. The cleaning solutions utilized on these operations shall be applied by immersing, spraying, wiping, circulating, or in any other manner as long as the surfaces to be cleaned are completely wetted in the solutions. Any component which can trap or retain liquids shall be drained or emptied between applications of different cleaning solutions.

All solutions shall be made with distilled, deionized, or clean tap water and all chemicals shall be of chemically pure grade or better. The water shall be filtered through a 40-micron nominal-size filter.

3.2.1 Degreasing

Components fabricated of stainless steel, aluminum, and aluminum alloys can be degreased by cold-flushing or vapor degreasing with trichloroethylene, or by flushing with a mild alkaline solution containing from 5 to 7 oz of Turco #4090* (or equivalent) per gallon of water at 140 to 160 F. The application of the mild alkaline solution shall be followed by a thorough water rinse.

Nonmetallic components, such as O-rings, gaskets, etc., shall be degreased by immersion or scrubbing with the mild alkaline solution described above, followed by a thorough water rinse.

Items which are not to be cleaned any further, such as nonmetallic components or simple components fabricated of machined aluminum stock, shall be dried by flushing with dry, hydrocarbon-free, filtered nitrogen gas, or by heating in an oven at 140 to 160 F.

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*Turco #4090 is furnished by Turco Products, Inc., 6135 So. Central Avenue, Los Angeles, California.

3.2.2 <u>Descaling</u>

Newly fabricated or reworked components which have scale resulting from welding or heat treatment, or impurities resulting from casting or forging, shall be descaled. Descaling solutions should not be used after precision machining unless the finished surfaces are protected.

The descaling of stainless steel components is accomplished as follows:

1. Etch at room temperature for a period of no longer than 60 minutes with an aqueous solution containing from 3 to 5 weight percent technical grade hydrofluoric acid and from 15 to 20 weight percent technical grade nitric acid.
2. Rinse thoroughly with water to remove all traces of the scaling solution.

NOTE: If the components are to be immediately passivated after descaling, they need not be dried. Otherwise, the components may be dried by purging with dry, hydrocarbon-free, filtered nitrogen gas or by heating in an oven at 140 to 160 F.

The descaling procedure for components fabricated of aluminum or aluminum alloys is as follows:

1. Clean with Turco Smut-Go* solution (1 lb/gallon of water), or an approved equivalent cleaner, until the surfaces are visibly clean and shiny.

*Turco Smut-Go is a chromic acid cleaner furnished by the Turco Products, Inc., 6135 So. Central Avenue, Los Angeles, California

2. Rinse with water to remove all traces of the acid solution. If the components are to be immediately passivated after descaling, they need not be dried. Otherwise, the components may be dried by purging with dry, hydrocarbon-free, filtered nitrogen gas or by heating in an oven at 140 to 160 F.

3.2.3 Passivation

The passivation procedure for components fabricated of stainless steel is as follows:

1. Immerse for a minimum period of 30 minutes, at room temperature, in an aqueous solution containing from 45 to 55 percent (by weight) technical grade nitric acid.
2. Rinse with water to remove all traces of the passivating solution.
3. Dry by purging with dry, hydrocarbon-free, filtered nitrogen gas or by heating in an oven at 140 to 160 F.

NOTE: Acid passivation of components having highly polished or lapped surfaces may be omitted if the finished surfaces cannot be conveniently protected from the acid solution.

Components fabricated of aluminum or aluminum alloys can be passivated as follows:

1. Immerse for a minimum period of one hour, at room temperature, in an aqueous solution containing about 45 percent (by weight) technical grade nitric acid.
2. Rinse thoroughly with water to remove all traces of nitric acid.

3. Dry by purging with dry, hydrocarbon-free, filtered nitrogen gas or by heating in an oven at 140 to 160 F.

3.2.4 Handling

Items that have been prepared for nitrogen tetroxide service shall be handled, stored, or packaged in such a manner as to prevent recontamination. Large components such as valves, piping sections, tanks, etc., should have all openings capped with clean compatible materials. Small items can be sealed in clean plastic bags.

4.0 HAZARDS

4.1 Toxicity

Nitrogen tetroxide, like other oxides of nitrogen, is very toxic and inhalation of even dilute concentrations should be avoided. Exposure of the skin to liquid or vapor nitrogen tetroxide is also to be avoided. In 1960, a maximum allowable concentration (MAC) of 5 ppm (designated as "nitrogen dioxide") in air for an eight-hour day continuous exposure, was adopted by the American Conference of Governmental Industrial Hygienists. From recent experience, it appears that exposures of 50 to 75 ppm can be tolerated for short periods of time.

Nitrogen tetroxide vapor, at ambient temperatures, have a characteristic reddish-brown color, which in good light, becomes apparent at about 50 ppm. It should be noted that the propellant vapor cannot be seen at safe concentrations.

Nitrogen oxides are particularly treacherous in that they have a mild odor and produce no strong immediate irritation; however, they produce a very strong delayed action several hours later. If an individual is exposed to strong concentrations, he should hold is breath, if possible, until fresh air is reached. If unable to do this, breathing should be as shallow as possible. The exposed individual should be placed in the care of an authorized physician as soon as possible. In the meantime, first-aid treatment can be administered as directed by the local medical authority. For this purpose, it is recommended that at least one person permanently assigned to the storage area be properly trained in first-aid techniques. These techniques must be established only by the responsible medical authority.

4.2 Physiological Effects

Precise proof is lacking that nitrogen oxides, as such, are irritant or toxic; however, in the atmosphere or in living bodies they form compounds which are irritant and intoxicant. Every milligram of nitrous gases entering the body, yields through chemical reaction, more than a milligram of nitrous and nitric acids. Before these acids are neutralized, pulmonary irritation may occur leading to upper respiratory tract and pulmonary edema, laryngitis, bronchitis, and pneumonitis. In humans, the occurrence of this characteristic edema may not be detectable immediately, but it is usually delayed for 6 or more hours. Later, the patient may complain of dizziness, headache and weakness; this may be followed by difficult breathing. Should the patient recover from this edematous condition, he would be susceptible to bacterial invasion of the lungs and consequent pneumonitis.

Any person who has or may have inhaled a considerable quantity of nitrogen tetroxide vapor should be kept under hospitalization or medical observation for a period of 24 hours since the person may be developing symptoms without being aware of it.

The effect of liquid nitrogen tetroxide spillage on the skin is similar to that caused by a 65-percent nitric acid solution. The gas, which is less corrosive for the same contact time, causes a stinging sensation similar to that of nitric acid fumes. The reaction is local however, and generally there will not be sufficient penetration of the body to produce toxic effects.

If a person has suffered skin or eye exposure to liquid or vaporized nitrogen tetroxide, the exposure areas should be washed immediately with copious quantities of water for at least 15 minutes. The affected individual should be placed in the care of an authorized physician as soon as possible.

4.3 Fire and Explosive Hazards

Although nitrogen tetroxide is very reactive chemically as an oxidizer, it is insensitive to mechanical shock, external heat, and detonation. The hazard associated with nitrogen tetroxide lies not in its flammability or explosiveness, but in its high reactivity and ability to support combustion and form explosive mixtures with combustible substances. As a result, storage and use areas should be kept free of all litter, rubbish, solvents, and other combustibles.

5.0 HAZARD REDUCTION

Spills of nitrogen tetroxide present a hazard from both intoxication and fire as described in the HAZARDS section. For this reason, it is necessary to prevent propellant spills whenever possible and to control the spills and fires safely when they occur.

5.1 Spill Prevention

The prevention of nitrogen tetroxide spills is one of the most important considerations for the safe handling of the propellant. Spills are the main cause of personnel intoxication and facility damage. Effective spill reduction is accomplished by the use of properly designed equipment and thoroughly trained personnel.

5.1.1 System Integrity

The integrity of the storage and transfer system cannot be overemphasized. The system shall be reliable, flexible, and easy to operate and maintain. Some of the design criteria that shall be incorporated on the system are as follows:

1. Only materials of construction which are definitely known to be compatible with the oxidizer shall be employed
2. The number of mechanical joints shall be reduced to a minimum, thus reducing the probability of propellant leakage
3. The system shall be designed to withstand the maximum operating pressure safely
4. The transfer lines shall be free of liquid traps
5. An inert-gas system must be provided to purge the transfer lines without the necessity of dumping the residual propellant or disconnecting any system joints

6. The system components must be reliable, compatible with the oxidizer, and properly serviced

7. The nitrogen tetroxide vents shall be ducted together and connected to a vapor scrubber or a high vent stack

8. Sufficient control equipment must be provided in order to isolate portions of the system during emergencies or components replacement

The continual observation of an operational system for possible malfunctions can prevent serious propellant spills. The leakage of nitrogen tetroxide vapors becomes obvious because of the reddish-brown color of the oxidizer and the tainted surface surrounding the leaking area. Thus, if a small leakage is noted, corrective action must be taken as soon as possible.

5.1.2 Trained Personnel

Properly trained personnel are required to handle nitrogen tetroxide safely. Operating personnel shall be thoroughly familiar with the following:

1. The properties of nitrogen tetroxide
2. Operation of the transfer and storage system
3. Toxicity and physiological effects of the propellant
4. Operation and use of the safety equipment
5. Fire and spill prevention techniques
6. Fire and spill control measures
7. Disposal and decontamination techniques
8. Local operating procedures and regulations

NOTE: No person should be allowed to handle nitrogen tetroxide unless he is thoroughly familiar with the aforementioned items and he is also confident that the propellant can be handled safely with the equipment and facilities available to him.

5.2 Fire Prevention

Nitrogen tetroxide, although not flammable nor explosive in air, is a highly reactive oxidizer agent and should not be permitted to come into contact with organic or combustible materials. To prevent fires in case of propellant spillage, the storage and handling areas shall be kept free of litter, rubbish, solvents, and other combustibles.

6.0 HAZARD CONTROL

In case of nitrogen tetroxide spillage or fire, all personnel shall report to their predesignated safe areas or emergency operating posts. Immediate evaluation of the hazardous situation is necessary so that appropriate control action can be initiated in the shortest possible time.

The time period between the inception of the hazardous situation and initiation of control action shall be reduced to a minimum. This can be accomplished through proper planning, training, and organization. The following items shall be considered in the administration of the storage and handling areas:

1. Safe areas and evacuation routes shall be pre-established
2. Only authorized personnel shall be allowed to enter these areas
3. At least two operating personnel shall wear protective clothing and equipment during propellant handling operations
4. Periodic drills shall be performed to ensure personnel proficiency during emergency operations

6.1 Spill Control

A propellant spill can be most efficiently controlled by performing the following steps chronologically:

1. Stop the propellant handling operations
2. Isolate, by closing the necessary valves, the propellant tanks from the transfer lines
3. Locate the source of spill

4. Isolate the affected components by closing the necessary valves

5. Dispose of the spilled propellant

The performance of the first four steps listed above should be automatic and can be performed in a very short time.

The disposition of the spilled propellant should not be too difficult, especially when propellant handling is performed only during satisfactory weather conditions and the first four steps listed above are quickly executed. The disposition method depends greatly on the quantity of propellant spilled, prevailing weather conditions, location of storage and/or handling area, etc. Therefore, the discussion presented herein will be limited to general criteria which will be applicable to most situations.

If the quantity of spilled propellant is small and the vapor is diffused rapidly and safely, the propellant can be allowed to vaporize until depletion. The spilled propellant can also be disposed of by deluging the spill area with copious quantities of water. The water not only reacts with the tetroxide to form nitric acid, but also increases the rate of propellant vaporization. However, if the quantity of spilled propellant is small and a properly designed water fog system is used, the amount of tetroxide vapor leaving the spill area is reduced significantly.

The control techniques applicable to large nitrogen tetroxide spills are dependent upon the maximum tolerable propellant vaporization rates. A minimum rate is experienced when the spilled propellant is allowed to vaporize until depletion. However, a

large amount of vapor is still generated over a relatively long period of time. Deluging the spill area with copious quantities of water would deplete the propellant in a very short period of time; however, the propellant vaporization rate is drastically increased. A water fog system would have little effect in reducing the amount of tetroxide vapor leaving the spill area.

After the spill is controlled, the entire area must be thoroughly decontaminated. Decontamination techniques are presented in another section of this document.

6.2 Fire Control

The criteria presented for spill control is equally effective for controlling fires. In this instance, however, the fire constitutes an additional hazard. The heat generated by the fire can damage mechanical and electrical components and weaken structural members. The water deluge technique is especially effective under these conditions since it not only controls the spill but also reduces the temperature of the materials exposed to the fire.

7.0 SAFETY EQUIPMENT

The toxicity and chemical reactivity of nitrogen tetroxide dictate that appropriate safety equipment must be provided for the protection of the storage and handling areas, and operating personnel. Although it is recognized that the type of personal safety equipment depends upon several factors such as facility design and personnel assigned tasks, it is suggested that only one type of safety equipment be specified and enforced. This criteria reduces the misunderstanding among operating personnel as to what degree of protection is required for a specific job assignment and prevents "short-cut" methods which are difficult to spot-check and which can result in serious accidents.

7.1 Facility Safety Equipment

Facility safety equipment shall consist of personnel emergency showers, eye baths, water deluge system (preferably of the fog type), fire blankets, portable fire extinguishers, first-aid kits, and fire hoses. This equipment shall be strategically located and easily accessible.

All operating personnel shall be thoroughly familiar with the location and operation of each piece of safety equipment. The operation of the safety equipment must be verified periodically.

The installation of a nitrogen tetroxide vapor detector is recommended in poorly ventilated facilities. This is necessary because the color of nitrogen tetroxide becomes apparent at 50 ppm, whereas the maximum allowable concentration (MAC) is only 5 ppm.

7.2 Personal Safety Equipment

Personnel handling nitrogen tetroxide should wear fully protective equipment. If the operations are performed remotely, it is still recommended that at least two operating personnel be fully dressed to facilitate proper spill and fire control.

The following personnel protective equipment, or its equivalent, is recommended:

1. Flameproof coveralls
2. Suit, Gra-Lite
3. Gloves, polyethylene impregnated
4. Hood, Gra-Lite
5. Boots, Gra-Lite
6. Respirator, self-contained or air-line connected

The above equipment must be maintained clean and in good operating order. A contaminated suit, for example, can become a definite safety hazard.

> NOTE: The above equipment recommendation is based only on its proven compatibility characteristics and commercial availability. However, the equipment is heavy, uncomfortable, and bulky. A need for more appropriate personal safety equipment definitely exists.

8.0 DECONTAMINATION

Decontamination involves the removal of nitric acid from the handling and storage areas following a propellant spill and the deactivation of facility equipment exposed previously to nitrogen tetroxide. On both occasions, decontamination procedures are employed to protect personnel and equipment. Personnel performing decontamination operations shall wear the fully protective equipment described in the SAFETY EQUIPMENT section.

8.1 Area Decontamination

The primary contaminant remaining from a propellant spill is the nitric acid formed from the reaction of the nitrogen tetroxide with water. Because this acid is extremely corrosive, it must be removed; this can be effected by washing the area with copious quantities of water. The drained water becomes, in turn, contaminated with the acid and must be disposed of as stipulated by local regulations.

The removal of nitric acid can be effected also by washing the contaminated area with a soda ash-water solution or other mild alkali solution. The removal of the acid, in this case, is based on reacting the acid with a chemical yielding soluble salts and water as reaction products. The treated areas must be rinsed subsequently with water to remove the excess of alkali solution, which can also be corrosive. The drained solution must be disposed of according to local regulations.

8.2 Equipment Decontamination

The removal of a component from a nitrogen tetroxide system must be preceded by a thorough gas purge to remove any residual

propellant. If the removed component is to be reused without service or modification, no further decontamination operations are required. Otherwise, the removed component is purged thoroughly with water and dried by purging it with gaseous nitrogen.

All components removed from a nitrogen tetroxide system must be labeled clearly, describing the extent of decontamination and operational status.

9.0 TRANSPORTATION

Shipment of nitrogen tetroxide in quantities of up to 10,000 gallons has been authorized by the Interstate Commerce Commission (ICC). The propellant is classified by the ICC as a "Class A, Poisonous Gas," and as such is subject to those regulations established for this group. In transit, cylinders must be affixed with a poison gas label (white) as specified in the regulations. Truck and rail cars containing nitrogen tetroxide must be identified with "Poison Gas" placards in letters at least 3 inches high on a contrasting background. As a poison, it is not acceptable for rail express shipment. Interconnecting cylinders by any means while in transit is strictly prohibited. Safety relief devices which would allow release of vapor to the atmosphere are prohibited. The cylinder fittings are encased in gas-tight protective caps to prevent leakage and damage.

The following containers have been ICC approved and are currently being used by the propellant manufacturer:

1. Cylinders (high-pressure seamless steel)

ICC-3D480	10 lb net and 156 lb net
ICC-3A2015	13 lb net
ICC-3A1800	125 lb net

2. Cylinders (forged steel, welded)

ICC-106A500-X	2000 lb net

3. Tank cars (single unit cars)

ICC-105A500-W	10,000 gal

Details and dimensions of the 13-lb and 125-lb-capacity nitrogen tetroxide cylinders are shown in Fig. 3 and 4, respectively. These cylinders are closed by a screwed plug. The 10-, 156-, and 2000-lb cylinders are equipped with stainless-steel valves; the details and dimensions are shown in Fig. 5, 6, and 7, respectively.

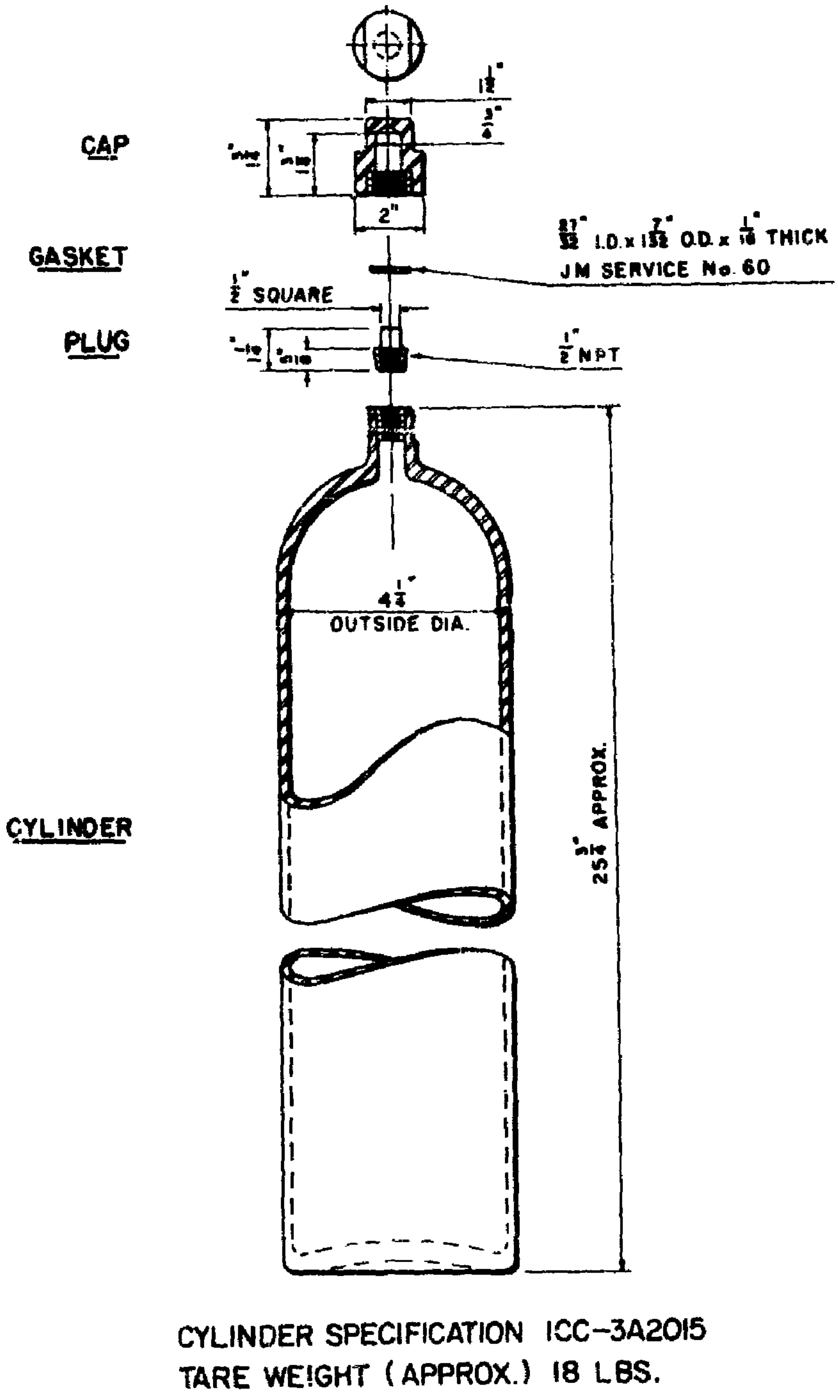
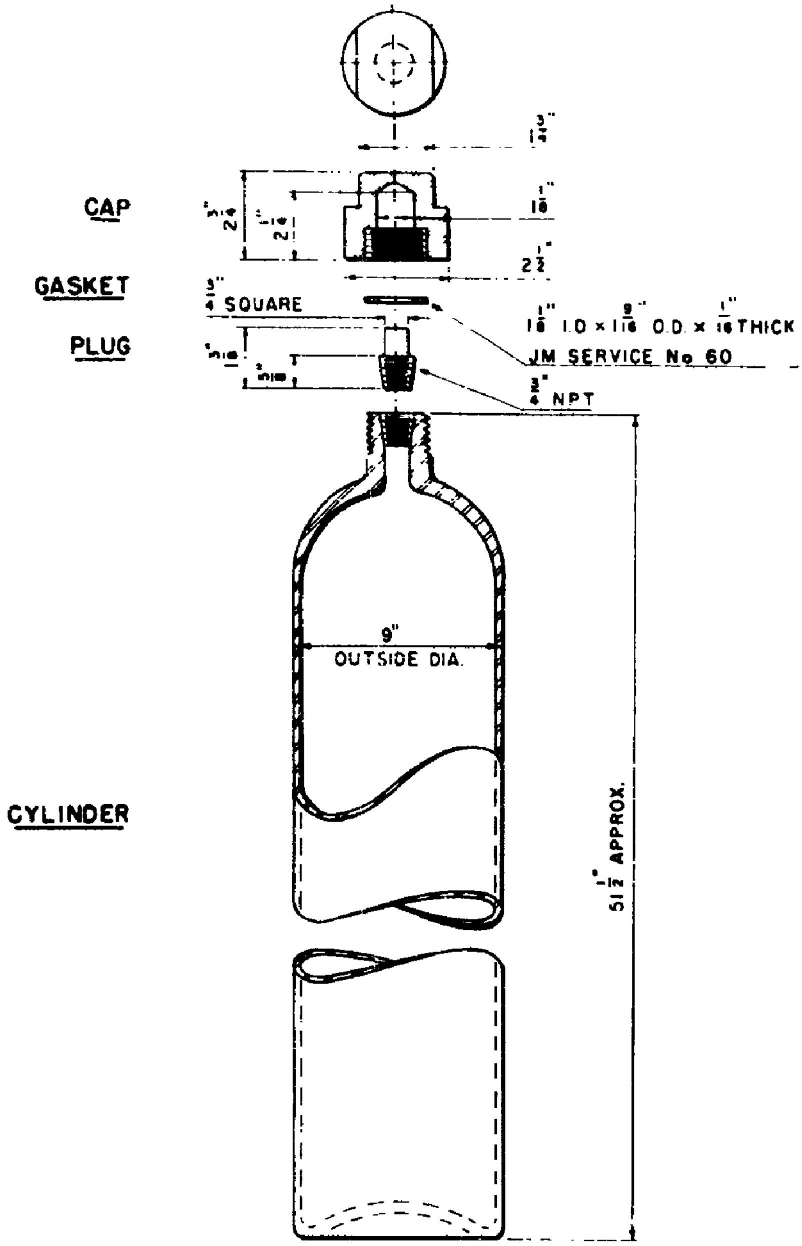
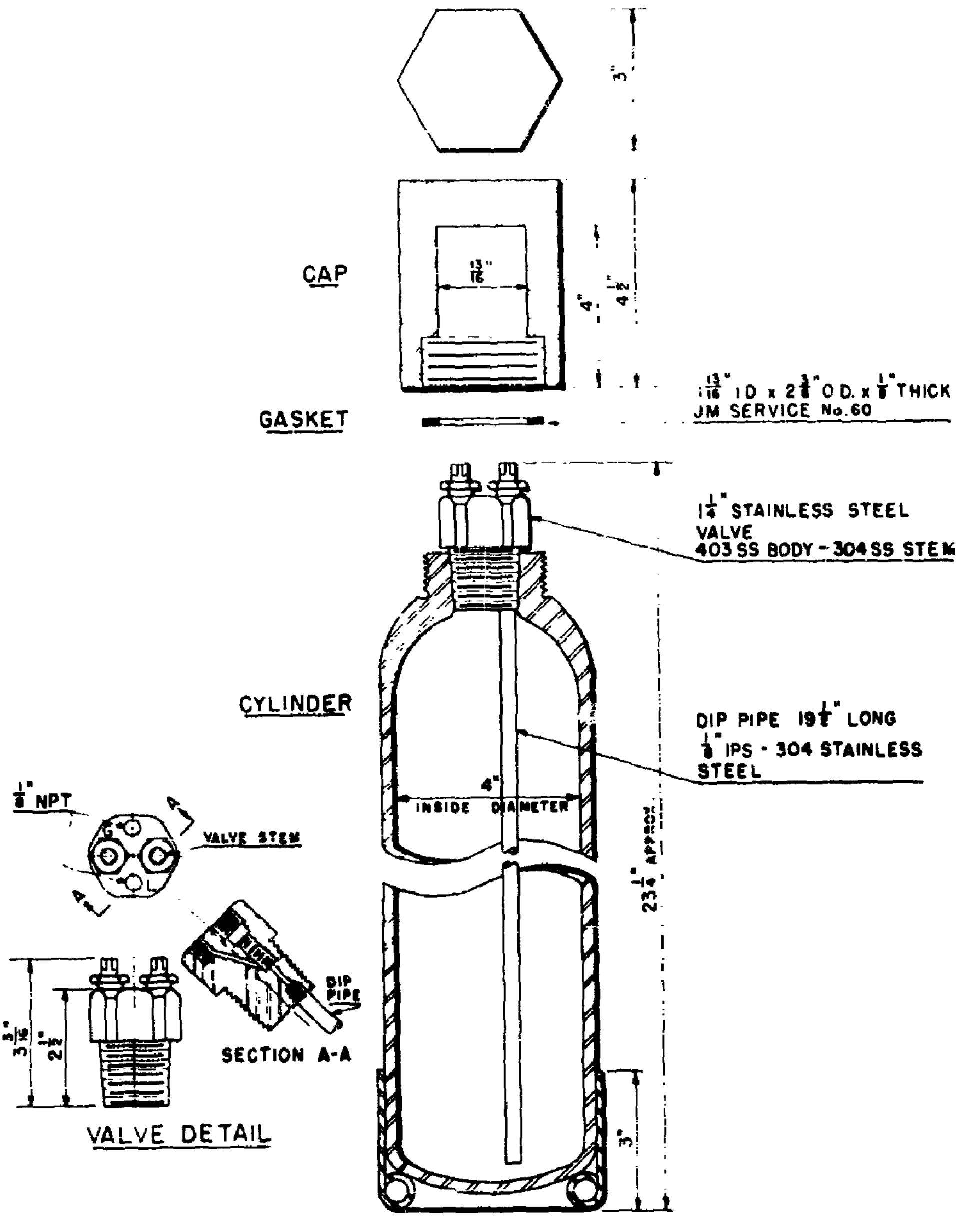


Figure 3. Details and Dimensions of 13 - lb Capacity Nitrogen Tetroxide Cylinder



CYLINDER SPECIFICATION ICC-3A1800
TARE WEIGHT (APPROX.) 127 LBS.

Figure 4. Details and Dimensions of 125 - lb Capacity Nitrogen Tetroxide Cylinder



CYLINDER SPECIFICATION ICC-3D480
TARE WEIGHT (APPROX.) 31 LBS.

Figure 5. Details and Dimensions of 10 - lb Capacity Nitrogen Tetroxide Cylinder

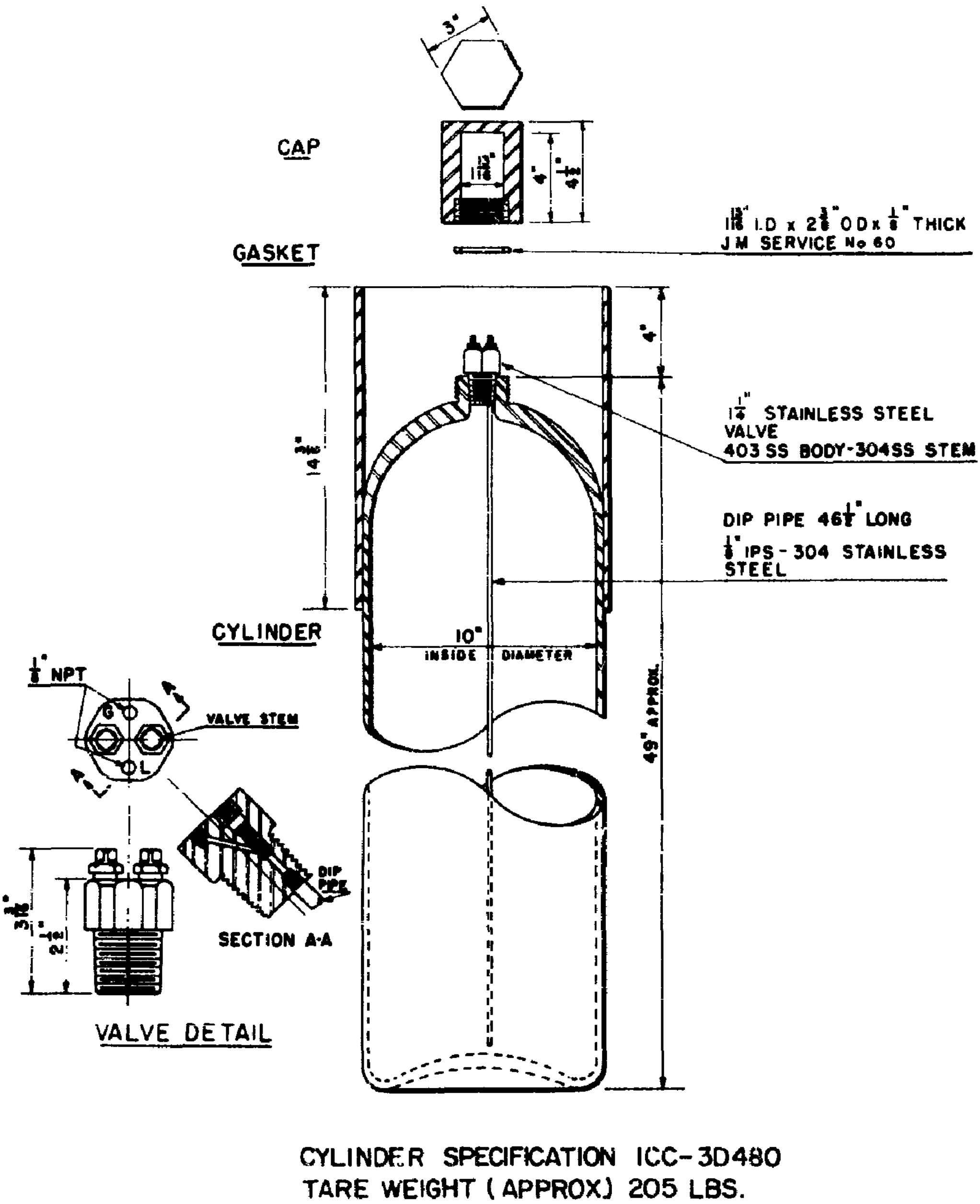


Figure 6. Details and Dimensions of 156 - lb
Capacity Nitrogen Tetroxide Cylinder

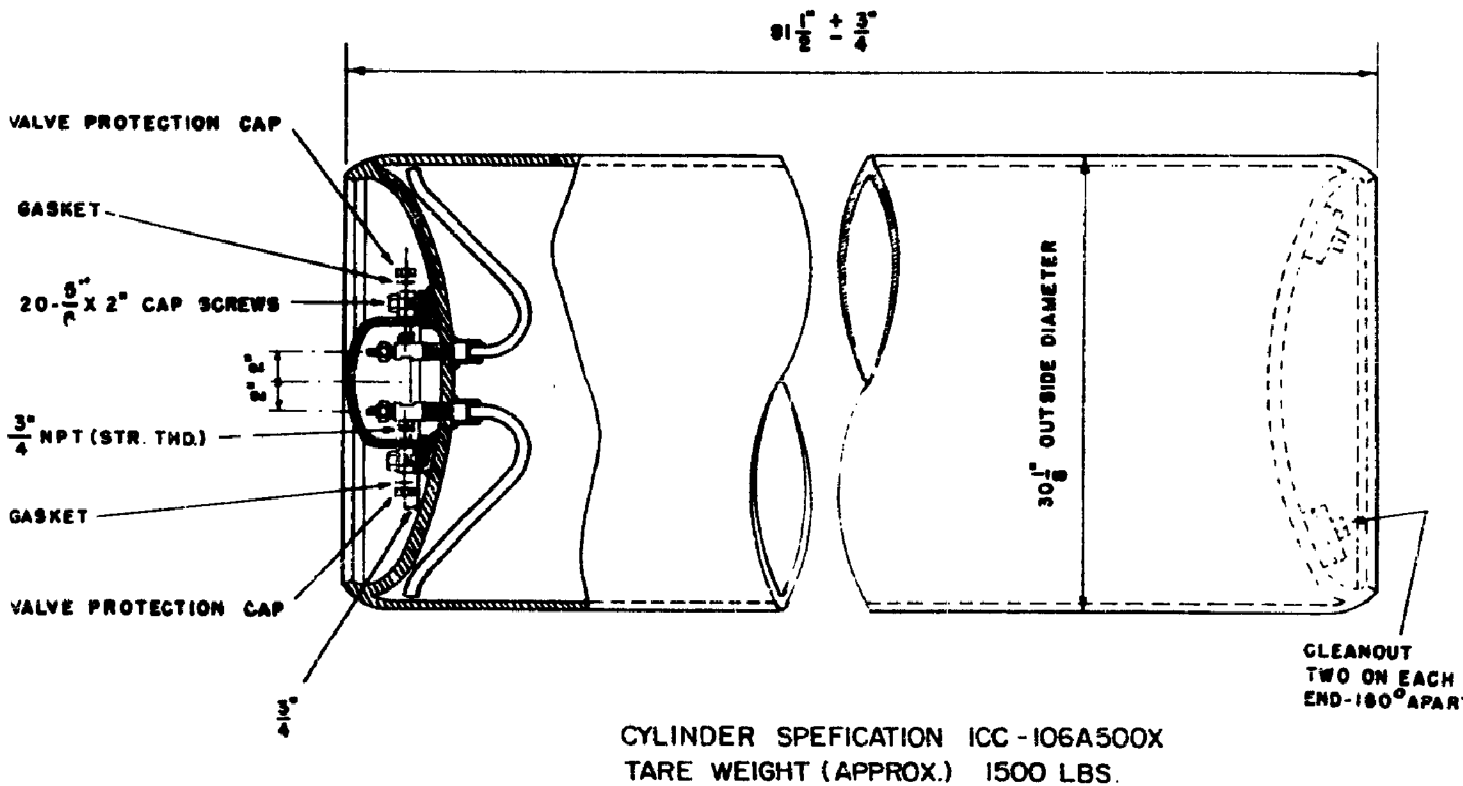


Figure 7. Details and Dimensions of 2,000 - lb Capacity Nitrogen Tetroxide Cylinder

10.0 STORAGE

Nitrogen tetroxide can be stored for periods of several years without adverse effects to the container and propellant. Such extended storage can be obtained only in clean, moisture-free, closed systems. The ICC-approved containers in which the propellant is transported can be used for temporary storage. Facility storage and use tanks should be fabricated of stainless steel because the possibility of moisture contamination is to be expected.

Nitrogen tetroxide is classified by the U. S. Air Force General Safety Procedures for Chemical Guided Missiles Propellants, as a "Group 11, Class A, Poisonous Substance," thus placing it in the same category as liquid fluorine. This document, T.O. 11C-1-6, dated 1956, is the present authority for establishing quantity-distance relationships for the storing of most of today's liquid rocket propellants. The quantity-distance values presently established for nitrogen tetroxide "Poison Hazard" are presented in Table 1.

Nitrogen tetroxide cylinders must be located and positioned so that they are secured against rolling or being inadvertently tipped over. This can be accomplished by placing them in cradles. Cylinders of capacity less than 2000 lb of nitrogen tetroxide can be placed vertically and secured with chains. Individual cylinder support is preferred.

When tank cars are used to store the propellant, the brakes must be set and the wheels chocked.

TABLE 1

APPLICABLE QUANTITY-DISTANCE VALUES FOR NITROGEN TETROXIDE

(T.O. 11C-1-6, dated 1956)

Quantity of Nitrogen Tetroxide		Barricaded Distance in Feet To:				Unbarricaded Distance in Feet to:
Pounds over	Pounds not over	Inhabited or Service Building**	Passenger Railroad*	Public Highway*	Magazine or Another Group XI Storage (Z)	Magazine or Another Group XI Storage
10	1,000	5,000	305	155	100	200
1,000	5,000	5,000	450	225	150	300
5,000	10,000	10,000	520	260	200	300
10,000	50,000	10,000	840	420	200	400
50,000	100,000	10,000	1,090	545	400	500
100,000	250,000	10,000	1,295	650	500	800

* American Table of Distances (double these if storages are unbarricaded).

** For distances from storages (except ready storages) to operating building, use (Z) inhabited building distances.

11.0 HANDLING

Nitrogen tetroxide handling operations, as described herein, includes the unloading of shipping containers, loading of storage tanks, venting, and disposal operations. Personnel performing these functions must wear the fully protective equipment described in the SAFETY EQUIPMENT section. Another activity closely associated with the above operations is the handling of the shipping containers. The shipping containers can be handled safely without the need of fully protective equipment.

11.1 Handling of Shipping Containers

The shipping containers must be handled gently and carefully. They must not be dropped, tumbled, dragged, or allowed to bump into other containers, walls, or projections. The containers' protective caps must be installed at all times during handling operations.

The containers may be transferred by means of truck, crane, forklift, or any other piece of equipment capable of handling them safely. While in transfer, the containers must be firmly secured.

Storage of the shipping containers should be restricted to those areas specifically allocated for this purpose. The condition of each container (full, empty, contaminated, etc.) should be marked clearly.

11.2 Transfer of Nitrogen Tetroxide

Nitrogen tetroxide can be transferred using several methods. The propellant can be discharged by its own vapor pressure, or by pressurizing the container with dry nitrogen or air, or by connecting

a transfer pump in the discharge line. Although these transfer methods have been used in the past, the discharge of the propellant appears to be most reliably performed by pressurizing the container with dry nitrogen.

The propellant transfer system must be chemically compatible and in good operating order.

In preparing for a transfer operation, all personnel not directly concerned with the operation shall evacuate the hazard area. Appropriate warning lights and signs should be displayed to keep out unauthorized personnel. Personnel performing the transfer operation shall wear the fully protective equipment described in the SAFETY EQUIPMENT section. If the operations are performed remotely, at least two operating personnel should be fully dressed to facilitate proper spill and fire control. Sufficient safety equipment should be available for all personnel allowed to remain in the hazard area. Supervisory and emergency support personnel shall be notified prior to executing any hazardous operation in the storage area.

The propellant transfer procedures are dependent upon numerous factors such as transfer system design, type of propellant container, training of operating personnel, prevailing weather conditions, etc. Establishing proper operating procedures for each specific situation in a single document is practically impossible. Therefore, the procedures presented below are general in nature. The transfer system schematics presented are not finalized designs; they are provided only to facilitate the explanation of typical procedures.

11.2.1 Transfer From Single-Opening Containers

The 13- and 125-lb-capacity nitrogen tetroxide cylinders (Fig. 3 and 4) are single-opening containers. The opening is sealed by means of a screwed plug which in turn is protected by a gas-tight cap. These cylinders should be avoided whenever possible since they present additional propellant transfer complexity.

The propellant can be transferred from these cylinders by pre-pressurizing the cylinders with dry nitrogen or air prior to the transfer or by allowing the propellant to flow under its own vapor pressure. The vapor pressure transfer technique is inefficient, and in some cases impossible, unless the collecting tank is cooled. Therefore, the prepressurization technique is recommended for most transfer operations involving single-opening cylinders.

To initiate the propellant transfer operation, the cylinder opening plug must be replaced with a shutoff valve. This can be accomplished by the following procedures:

1. Secure the cylinder in the upright position,
2. Chill the cylinder and its contents with iced water to a temperature below 50 F,
3. After cooling, remove the protective cap and plug and install a compatible stainless-steel valve in the cylinder threaded opening. Use a compatible thread-lubricating compound on the valve thread. (Teflon tape is highly recommended as a lubricant and sealant for pipe threads.)

The prepressurization of the cylinder with dry nitrogen or air can be accomplished as follows:

1. Connect a regulated dry-nitrogen or air-pressure source to the shutoff valve of the cylinder.
2. Regulate the pressure supply to the desired value. The regulated pressure level determines the rate of propellant transfer; a value ranging from 50 to 100 psig is usually adequate. The pressure should never exceed 10 psig less than the cylinder design pressure.
3. Open the pressure supply shutoff valve.
4. Slowly open the cylinder shutoff valve.
5. When the cylinder pressure equalizes the regulated source pressure, close the pressure supply and cylinder shutoff valves. Two basic techniques can be used to determine when pressure equalization is attained: first, the noise generated by the gas flow through the pressurizing line ceases; and second, the regulated pressure gage registers the regulated pressure value prior to gas flow.
6. Bleed the trapped gas between the two shutoff valves by opening the transfer line bleed valve.
7. Disconnect the pressurizing line from the cylinder shutoff valve.
8. Cap the opened connections to prevent contamination.

The transfer of liquid nitrogen tetroxide from the pressurized cylinder to the storage tank (Fig. 8) can be performed as follows:

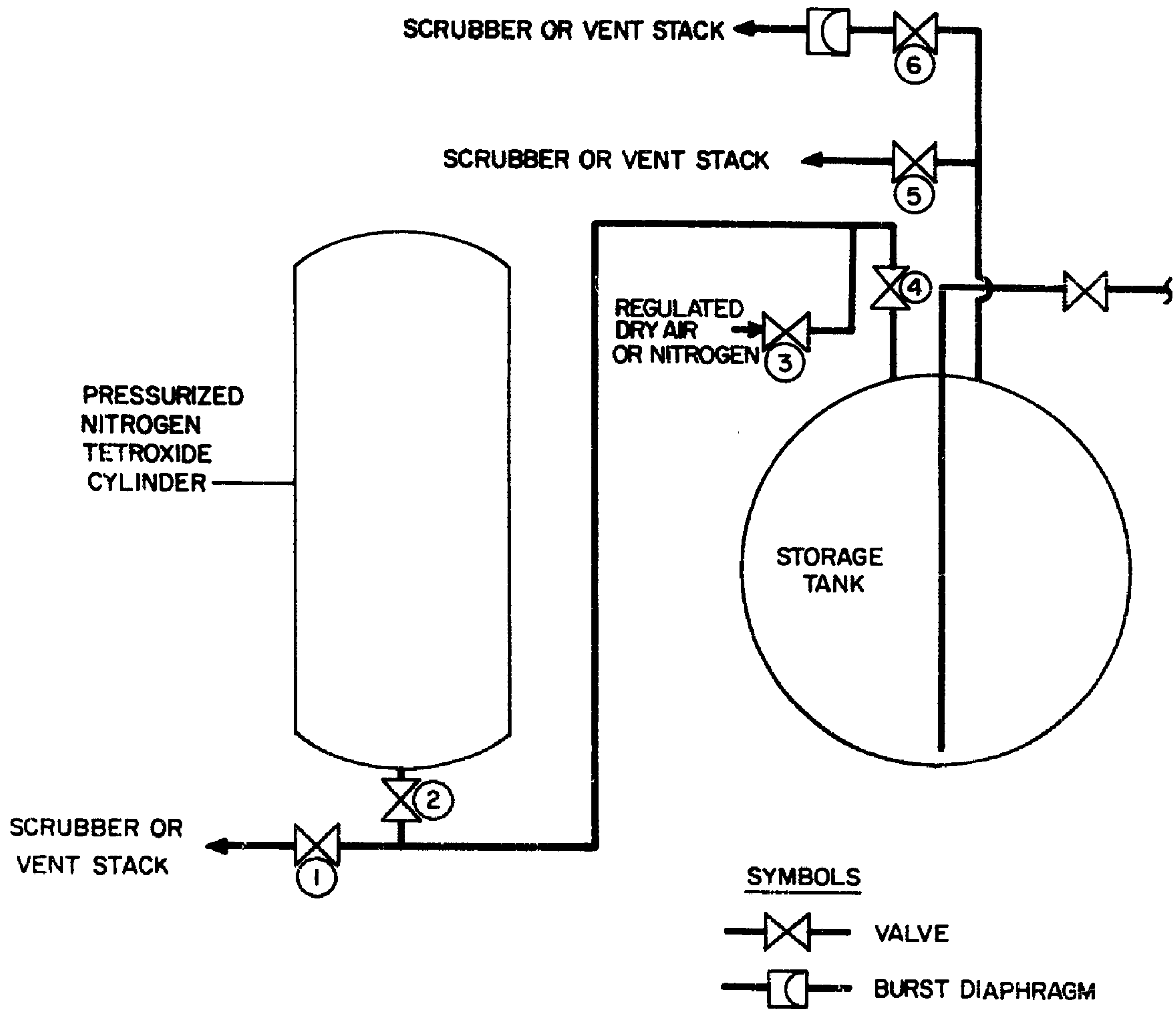


Figure 8. Transfer of Nitrogen Tetroxide from Pressurized Single-Opening Cylinders

1. Turn the cylinder upside down and place it in a transfer cradle. The cylinder must be properly secured and care must be exercised to prevent damage to the cylinder shutoff valve.

2. Connect the cylinder shutoff valve to the propellant transfer system as shown in Fig. 8.

3. Close all system valves except valve No. 6 which must be maintained open. The purpose of valve No. 6 is to prevent the continuous escape of nitrogen tetroxide in case of burst-diaphragm failure and to facilitate the removal of the burst diaphragm whenever required.

4. Purge the propellant transfer line to remove trapped water vapor. This is accomplished by opening valves No. 3 and 1. When the purge operation is completed (about 3 minutes), close valves No. 3 and 1.

5. Open valve No. 2 slowly and check for leaks. If a leak develops, close the valve, open valve No. 1, and take the necessary action to stop the leak. (Valve No. 1 must be closed and valve No.2 opened before proceeding with Step 6.)

6. Open valve No. 4.

7. After valves No. 2 and 4 have been opened, the propellant flows from the cylinder into the storage tank until the liquid in the cylinder is depleted or the pressure in the two containers equalizes. If the pressure in the two containers equalizes, close valve No. 4, and open, momentarily, valve No. 5 to depressurize the storage tank. The flow can be resumed by reopening valve No. 4.

8. When the desired quantity or all of the available propellant has been transferred, close valves No. 2 and 4.

   NOTE: There are several devices which can be used to detect the completion of the propellant transfer operation. Combinations of two or more devices are usually required to provide the desired flexibility of the transfer system. Some of these devices are:

   a. A flowmeter installed in the transfer line

   b. A scale or other weight-sensing device attached to the container being unloaded

   c. A calibrated level indicator mounted on the storage tank

9. Purge the transfer line thoroughly by opening valves No. 1 and 3. When the purging operation is completed (about 3 to 5 minutes), close valves No. 3 and 1.

10. Depressurize the storage tank by opening valve No. 5 momentarily.

11. Disconnect the cylinder shutoff valve from the transfer system and cap the opened components.

12. Turn the cylinder to the upright position and place it in the iced-water bath and allow it to cool.

13. Open the cylinder shutoff valve.

14. Remove the shutoff valve and install the cylinder plug and protective cap.

15. Decontaminate the shutoff valve (refer to the DECONTAMINATION section) and store it for future use.

16. The cylinder must be marked adequately and disposed of according to operating procedures.

17. Notify all personnel concerned that the transfer operation is completed and the area is clear.

11.2.2 Transfer From Double-Opening Containers

The 10-, 156-, and 2000-lb-capacity nitrogen tetroxide cylinders, as well as the truck and tank car vessels, are double-opening containers; in addition, they are fitted with shutoff valves. During transfer operations, one opening can be used to pressurize or vent the container and the other opening to discharge the propellant.

The propellant can be discharged from the shipping containers either by pressurizing the container with dry nitrogen or air, or by connecting a transfer pump in the discharge line. The pressurization technique is more reliable since no rotating machinery is employed on the transfer operation. Both transfer techniques are discussed in detail below.

11.2.2.1 Pressurization Unloading

As mentioned previously, the transfer of liquid nitrogen tetroxide from shipping containers can be performed reliably by pressurizing the containers with dry nitrogen or air. The following procedure is basically applicable to the transfer of the propellant from double-opening containers into a storage tank using gas pressurization:

1. Position and secure the container.
    (a) The 10- and 156-lb cylinders are placed in the upright position.

(b) The 2000-lb cylinder is placed in a horizontal position with the shutoff valves aligned with the vertical centerline axis.

(c) The truck or tank car is placed on a level position with the brakes locked and the wheels chocked.

2. Connect the container shutoff valves to the transfer system as shown in Fig. 9. The different containers are connected as follows:

   (a) 10- and 156-lb cylinders. The shutoff valve marked G (gas) is connected to the regulated pressure supply; the valve marked L (liquid) is connected to the transfer line.

   (b) 2000-lb cylinder. The upper shutoff valve is connected to the regulated pressure supply; the lower valve is connected to the transfer line.

   (c) Tank car. Connect the transfer line to either of the two valves located along the longitudinal axis of the tank; the regulated pressure line is connected to either of the two valves located 90 degrees apart from the liquid discharge valves. The transfer valves are located on top of the tank car.

3. Ensure that all the system valves are closed except valve No. 9 which must be maintained open. The purpose of valve No. 9 is to prevent the continuous escape of nitrogen tetroxide in case of burst-diaphragm

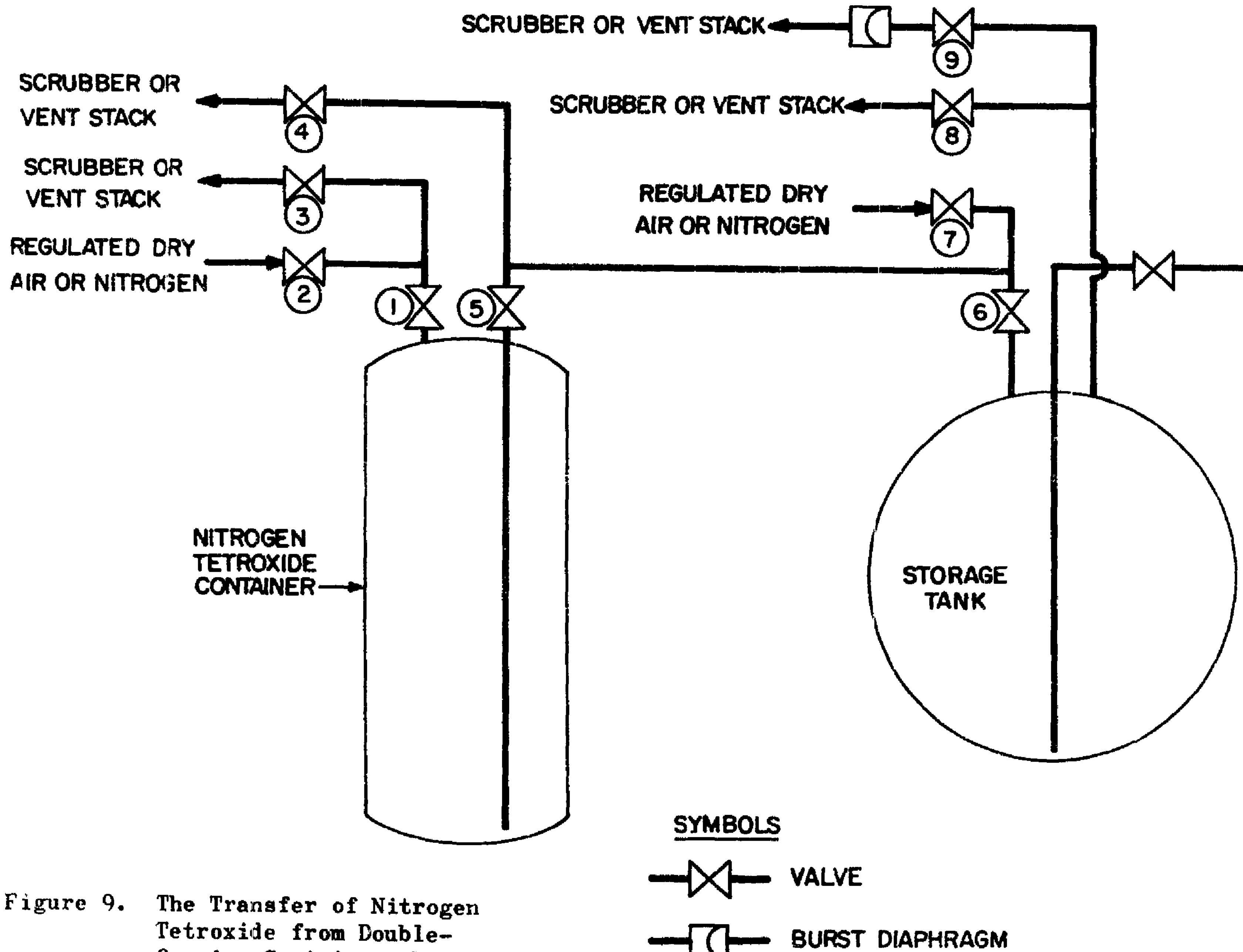


Figure 9. The Transfer of Nitrogen Tetroxide from Double-Opening Containers by Gas Pressurization

failure and to facilitate the replacement of the burst diaphragm whenever required.

4. Set the dry-nitrogen or air regulator to the desired pressure level. This pressure level determines the propellant discharge flow. A value ranging from 50 to 100 psig is usually adequate. The pressure should never exceed 10 psig less than the container design pressure.

   NOTE: The nitrogen tetroxide tank cars are equipped with flow-check valves which limit the flow of the propellant to about 5 to 6 gpm. To operate within this flow limit, the tank car pressure should be maintained at about 20 to 30 psig.

5. Purge the propellant lines to remove trapped water vapor. This can be accomplished as follows:

   (a) Open valves No. 4 and 7, and purge for about 3 minutes.

   (b) Close valves No. 7 and 4.

   (c) Open valves No. 3 and 2, and purge for about 3 minutes.

   (d) Close valves No. 2 and 3.

6. Open valve No. 5 and check for leaks. If a leak develops, close the valve, open valve No. 4, and take the action necessary to stop the leak. (Valve No.4 must be closed and valve No. 5 opened before proceeding with Step 7.)

7. Open valve No. 6.

8. Establish the propellant flow by pressurizing the nitrogen tetroxide container. This is accomplished by opening valves No. 1 and 2. A propellant flow is experienced until the liquid in the shipping container is depleted or the pressure in the two containers equalizes. If the pressure in the two containers equalizes, close valves No. 2 and 6, and open valve No. 8 momentarily. The flow can be resumed by reopening valves No. 6 and 2.

9. When the desired quantity or all of the available propellant has been transferred, close valves No. 2 and 5.

   NOTE: There are several devices which can be used to detect the completion of the propellant transfer operation. Combinations of two or more devices are usually required to provide the desired transfer system flexibility. Some of these devices are:

   a. A flowmeter installed in the transfer line

   b. A scale or other weight-sensing device attached to the container being unloaded

   c. A calibrated level indicator mounted on the storage container

10. Depressurize the shipping container by opening valve No. 3. When the container is depressurized, close valves No. 1 and 3.

11. Close valve No. 6 and purge the transfer line by opening valves No. 4 and 7. When the transfer line is properly purged (usually from 3 to 5 minutes at a purge pressure level of about 50 psig), close valves No. 7 and 4.

12. Depressurize the storage container by opening valve No. 8 for a short period of time.

13. Disconnect the shipping container shutoff valves from the transfer system and cap the opened components.

14. Mark and dispose of the shipping container according to operating procedures.

15. Notify all personnel concerned that the transfer operation is completed and the area clear.

11.2.2.2 Transfer Pump Unloading

As mentioned previously, pump unloading is an alternate method of transferring nitrogen tetroxide from the shipping containers into storage tanks. This technique is highly applicable when large quantities of the propellant must be transferred in a relatively short period of time.

The following procedure is basically applicable to the transfer of nitrogen tetroxide from double-opening shipping containers into a storage tank by means of a transfer pump.

1. Position and secure the shipping container

   (a) The 10- and 156-lb cylinders are placed in the upright position.

   (b) The 2000-lb cylinder is placed in a horizontal position with the shutoff valves aligned with the vertical centerline axis.

   (c) The truck or tank car is placed on a level position with the brakes locked and the wheels chocked.

2. Connect the container shutoff valves to the transfer system as shown in Fig. 10. The different containers are connected as follows:

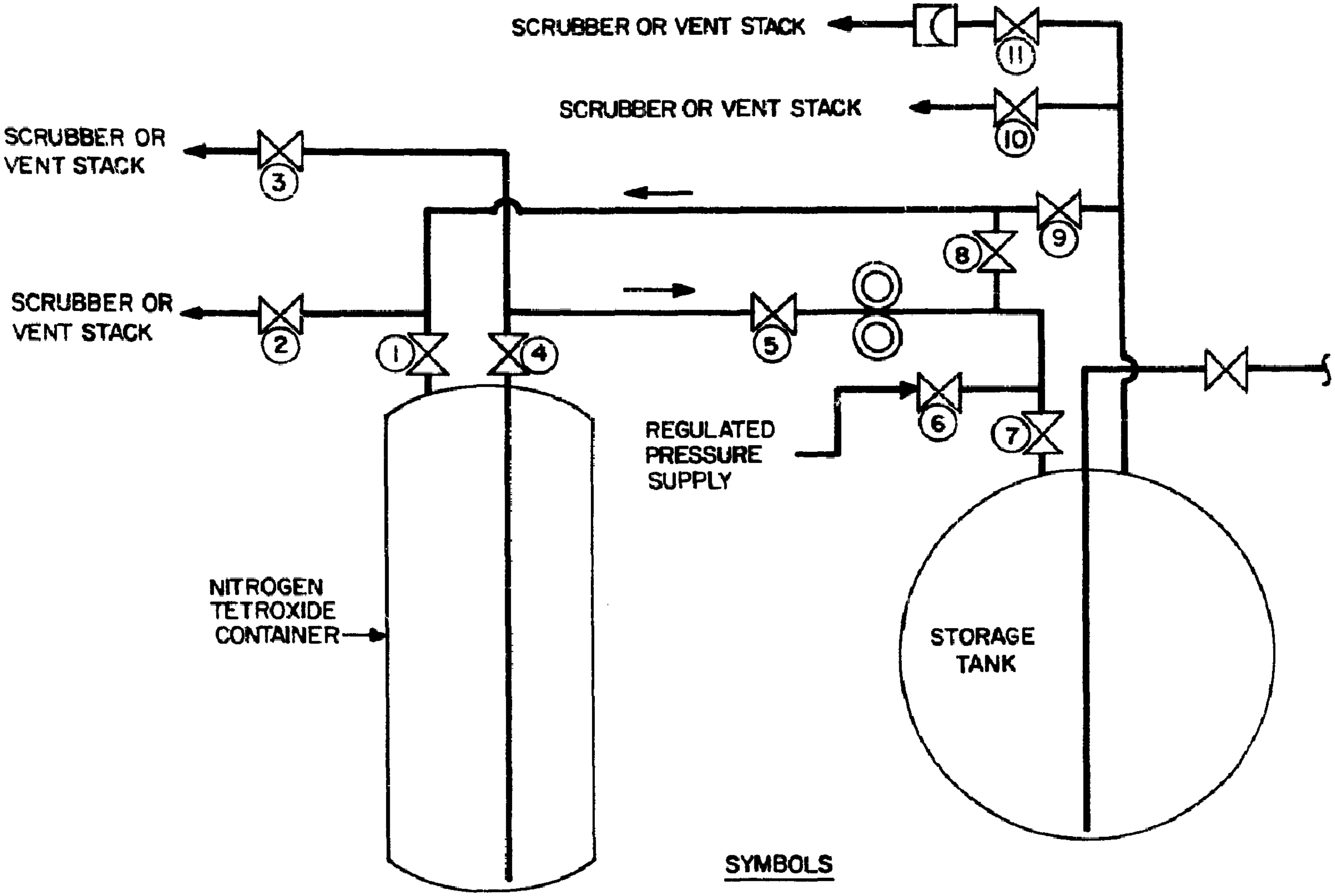
   (a) 10- and 156-lb cylinders. The shutoff valve marked G (gas) is connected to the vapor return line; the valve marked L (liquid) is connected to the transfer line.

   (b) 2000-lb cylinder. The upper shutoff valve is connected to the vapor return line; the lower valve is connected to the transfer line.

   (c) Tank car. Connect the transfer line to either of the two valves located along the longitudinal axis of the tank; the vapor return line is connected to either of the two valves located 90 degrees apart from the liquid discharge valves. The transfer valves are located on top of the tank car.

3. Ensure that all system valves are closed except valves No. 11 and 7, which must be opened. The purpose of valve No. 11 is to prevent the continuous escape of nitrogen tetroxide in case of burst-diaphragm failure and to facilitate the removal of the burst diaphragm whenever required. Valve No. 7 prevents pump damage due to overpressures resulting from the possible expansion of trapped propellant in the pump.

4. Set the dry nitrogen or air regulator to the desired pressure level. A value ranging from 20 to 30 psig should be adequate.



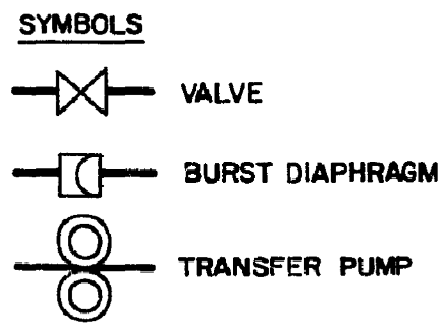


Figure 10. The Transfer of Nitrogen Tetroxide from Double-Opening Containers Using a Pump

5. Purge the propellant lines to remove trapped water vapor; this can be accomplished as follows:

   (a) Close valve No. 7

   (b) Open valves No. 3, 5, and 6, and purge for about 3 minutes

   (c) Close valves No. 6, 5, and 3

   (d) Open valves No. 2, 8, and 6, and purge for about 3 minutes

   (e) Close valves No. 6, 8, and 2

   (f) Open valve No. 7

6. Pressurize the nitrogen tetroxide container in order to ~~permit the~~ proper priming of the transfer pump, if required. This is accomplished as follows:

   (a) Close valve No. 7

   (b) Open valves No. 1, 8, and 6

   (c) When the gas flow stops, close valves No. 6, 8, and 1

   (d) Open valve No. 7

7. Open valve No. 4 and check for leaks. If a leak develops, close the valve, open valve No. 3, and take the necessary action to stop the leak. (Valve No. 3 must be closed and valve No. 4 opened before proceeding with Step 8)

8. Open valve No. 5 and check for leaks. If a leak develops, close valves No. 5 and 7, open valves No. 8 and 2, and take the necessary action to stop the leak. (Valves No. 2 and 8 must be closed, and valves No. 5 and 7 opened before proceeding with Step 9.)

9. Open valve No. 1.

10. Start the transfer pump and open shutoff valve No. 9. A closed-looped pump transfer operation is thus established.

11. When the desired quantity or all of the available propellant has been transferred, stop the transfer pump and close valve No. 7.

    NOTE: There are several devices which can be used to detect the completion of the propellant transfer operation. Combinations of two or more devices are usually required to provide the desired transfer system flexibility. Some of these devices are:

    (a) A flowmeter installed in the transfer line

    (b) A scale or other weight-sensing device attached to the container being unloaded

    (c) A calibrated level indicator mounted on the storage tank

12. Close valve No. 9 and depressurize the shipping container by opening valve No. 2. When the container is depressurized, close valve No. 2.

13. Depressurize the storage tank by opening valve No. 10 for a short period of time.

14. Purge the propellant transfer line as follows:

    (a) Open valve No. 6 for about 2 to 3 minutes or until the gas flow stops

    (b) Close valve No. 6

    (c) Close valve No. 4

    (d) Open valves No. 3 and 6, and purge the line for about 3 to 5 minutes

    (e) Close valves No. 6, 5, and 3

15. Depressurize the shipping container by opening valve No. 2. When the container is depressurized, close valves No. 1 and 2.

16. Purge the vapor return line as follows:

    (a) Open valves No. 2, 8, and 6, and purge for about 2 to 5 minutes

    (b) Close valves No. 6, 8, and 2

17. Open valve No. 7.

18. Disconnect the shipping container shutoff valves from the transfer system and cap the opened components.

19. Mark and dispose of the shipping container according to operating procedures.

20. Notify all personnel concerned that the transfer operation is completed and the area clear.

11.3 Venting

The depressurization of nitrogen tetroxide containers occurs quite frequently. In this operation, a considerable amount of nitrogen tetroxide vapor is released which must be handled safely. Two basic methods are generally used for handling the propellant vapor. These methods are:

1. The transfer system vent lines are connected to a scrubber system which removes the propellant vapor from the vented gases. Many types of scrubbers and solutions for absorbing the propellant vapors can be used.

2. The transfer system vent lines are connected to a vent stack which discharges the vented gases at least 50 feet above the highest working point in the area. In some cases, a dry nitrogen or air purge is installed in the vent stack to dilute the nitrogen tetroxide vapors before being discharged into the atmosphere.

Nitrogen tetroxide containers should be vented only under controlled conditions. These conditions are dependent upon area location, weather conditions, etc.

11.4 Disposal

Disposal involves the controlled release of nitrogen tetroxide from a shipping or storage container into a system capable of disposing of the propellant safely. Military regulations, at the present time, limit the disposal of nitrogen tetroxide and other propellants in its classification to a maximum of 1000 lb for any one disposal operation.

The following items are essential for the proper selection and operation of the nitrogen tetroxide disposal area:

1. The disposal area shall be isolated in accordance with the quantity-distance tables presented in the STORAGE section.
2. The disposal area shall be clear of trees, weeds, brush, and other combustibles.
3. The area must be provided with adequate facility safety equipment (see SAFETY EQUIPMENT section).
4. One person shall never be allowed to work in the disposal area alone.
5. The personal safety equipment, which was described in the SAFETY EQUIPMENT section, must be worn during disposal operations.
6. All personnel not participating in the disposal operation shall evacuate the area.
7. Disposal operations shall be conducted only under controlled conditions. These conditions are dependent upon area location, weather conditions, etc.

The following methods are usually employed for disposing of nitrogen tetroxide:

1. The slow release of the liquid or vaporized propellant through a high vent stack. The vent stack outlet should be at least 50 feet above the disposal area. A dry nitrogen or air purge may be installed in the stack to dilute the propellant vapor before being exhausted into the atmosphere.

2. The controlled burning of nitrogen tetroxide by the use of a fuel such as alcohol or kerosene. This is accomplished by placing a quantity of fuel approximately equal to the quantity of nitrogen tetroxide to be disposed of into a burn basin and then igniting the fuel. The nitrogen tetroxide is then sprayed over the burning fuel surface and the discharge flow adjusted until a very small amount of nitrogen tetroxide vapor can be seen dispersing into the atmosphere. For this operation, the nitrogen tetroxide supply tank should be located at least 50 feet from the burn basin.

AD-

Rocketdyne, a Division of North American Aviation, Inc., Canoga Park, California. NITROGEN TETROXIDE HANDLING MANUAL by E. Suarez-Alfonso, A.E.Chambers, and D.J. Hatz. September 1961, 58 p incl. illus. (Proj. 3148, Task 30196) (AF/SSD-TR-61-8) (Contract AF33(616)-6939)

Unclassified report

This manual presents directly usable information for the safe handling of nitrogen tetroxide. The properties of the propellant and techniques for (over)

UNCLASSIFIED

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2. Safe handling of liquid propellants
3. Liquid propellants

I. Suarez-Alfonso, E.
II. Chambers, A.E.
III. Hatz, D.J.

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